Lasers Med Sci (2014) 29:105–111
DOI 10.1007/s10103-013-1282-9

ORIGINAL ARTICLE

Visual outcomes of topography-guided excimer laser surgery for treatment of patients with irregular astigmatism

Mohammad Ghoreishi · Afsaneh Naderi Beni · Zahra Naderi Beni

Received: 3 June 2012 / Accepted: 4 February 2013 / Published online: 24 February 2013

Abstract The aim of this study was to evaluate the efficacy, safety, and predictability of topography-guided treatments to enhance refractive status following other corneal surgical procedures. In a prospective case series study, 28 consecutive eyes of 26 patients with irregular astigmatism after radial keratotomy, corneal transplant, small hyperopic and myopic excimer laser optical zones, and corneal scars were operated. Laser-assisted in situ keratomileusis (LASIK) (n=8) and photorefractive keratectomy (PRK) (n=20) were performed using the ALLEGRETTO WAVE excimer laser and topography-guided customized ablation treatment software. Preoperative and postoperative uncorrected visual acuity (UCVA), best corrected visual acuity (BCVA), manifest and cycloplegic refraction, and corneal topography with asphericity were analyzed in 12 months follow-up. Uncorrected visual acuity (UCVA) changed from 0.2±0.2 or (20/100±20/100) to 0.51±0.31 or (20/40±20/60) in the LASIK group (P=0.01) and from 0.34±0.16 or (20/60±20/120) to 0.5±0.23 or (20/40±20/80) in the PRK group (P=0.01). Refractive cylinder decreased from −3.2±0.84 diopters (D) to −2.06±0.42 D in the LASIK group (P=0.07) and from −2.25±0.39 D to −1.5±0.23 D in the PRK group (P=0.008). Best corrected visual acuity did not change significantly in either group. Topography-guided treatment is effective in correcting the irregular astigmatism after refractive surgery. Topography-guided PRK can significantly reduce irregular astigmatism and increase the UCVA and BCVA.

Keywords Refractive surgery · Topography-guided ablation · Irregular astigmatism

M. Ghoreishi
Isfahan University of Medical Sciences, Persian Eye Clinic,
P.O. Box 81655/599208, Mir St, Isfahan, Iran

A. Naderi Beni
Shahrekord University of Medical Sciences and Health Services,
Shahrekord, Iran

Z. Naderi Beni
Shahrekord, Iran

A. Naderi Beni (✉)
Kashani Hospital, Shariati St,
Shahrekord, Iran
e-mail: a_naderibeni@yahoo.com

Introduction

Refractive surgery was developed so that people could enjoy good vision with no or reduced dependence on glasses or contact lenses. Approximately 5 to 25 % of refractive procedures result with a less than satisfactory outcome postoperatively [1–9].

Aside from residual refractive error or overcorrection, these patients frequently have some form of irregular astigmatism. Refractive errors, such as residual astigmatism after elective refractive procedures and penetrating keratoplasty (PKP), are frequent and remain a challenge for surgeons of the anterior segment.

Residual astigmatism may be corrected with glasses or rigid contact lenses for irregular astigmatisms. When optical methods fail to achieve satisfactory visual rehabilitation, surgical procedures may be necessary, such as photorefractive keratectomy (PRK) [10] and laser in situ keratomileusis (LASIK) [11, 12]. In recent years, however, advancements in laser technology have offered better tools for dealing with irregular astigmatism [13].

In this study, we evaluated the safety, predictability, and efficacy of PRK and LASIK for correcting irregular astigmatism using the topography-guided photoablation and topography-guided customized ablation treatment (T-CAT) software of the ALLEGRETTO EYE Q.

Patients and methods

The study was approved by the Clinical Research Ethics Committee of the Iran University of Isfahan. In a prospective, non-comparative case series, 28 consecutive eyes (13 right and 15 left) of 26 patients (18 males and eight females) underwent PRK or LASIK between December 2007 and November 2008 in the Persian Eye Clinic. The median age was 40 years (range 23 to 50 years). Patients with irregular corneal astigmatism (corneal topography with irregular astigmatism, significant increase in higher-order aberrations, root mean square>0.55 at the 6 mm) due to previous corneal surgery or corneal scar who were dissatisfied with their quality of vision were included in the study. All patients were contact lens-intolerant and had subjective complaints of photophobia, halo vision, night vision problems, ghosting, starbursts, or monocular double vision when specifically asked during the preoperative assessment.

Patients with central corneal scars or central haze interfering with visual acuity, ectasias at corneal graft margins, irregular astigmatism caused by corneal ectasia or keratoconus, ablations leaving a residual corneal thickness ≤250 μm after treatment, interval less than 2 years (postkeratoplasty group) or 1 year (all other groups) after last surgery, and inability to complete the 12-month follow-up were excluded. A full ophthalmological examination was performed on all patients prior to surgery, including uncorrected visual acuity (UCVA) and best corrected visual acuity (BCVA) (were tested with the Snellen chart), manifest and cycloplegic refraction, slit-lamp examination with fundus evaluation, oculyzer wavelight and keratometry (Humphrey Model 599, Zeiss), wavefront assessment (wavefront analyzer, Wavelight) if possible, corneal topography (topolyzer, Wavelight), and ultrasonic pachymetry.

All patients were appropriately informed as to the experimental nature of the study, and written consent was obtained before surgery. Uniquely, the elevation data are statistically evaluated over two or more serial examinations to assure that the data have repeatability appropriate for use as surgical data. Eight repeatable and highly reproducible topography maps were obtained. The Topolizer software (Wavelight) uses <8 corneal topographies obtained in the automatic mode.

The topography height maps, together with the pupil size and position, were exported to the T-CAT software. Treatment was centered on the visual axis instead of the center of the pupil. The target asphericity for all eyes was set to $Q=-0.46$, which is believed to be the theoretical optimum for the eye's physiology according to Manns et al. and Probst and Machat [14, 15].

Surgical technique

Eight eyes had LASIK enhancement with a new cut or flap lift, whereas 20 eyes, due to the limitations in the corneal thickness, underwent PRK. All operations were performed using topical anesthesia.

For PRK, mechanical removal of the corneal epithelium accomplished by means of a 20 % ethanol for 20 s to create a central 6.0-mm zone centered over the pupil. The laser focused on the surface of Bowman's layer, and the cornea ablated while the patient fixated on target light under constant eye-tracking control. The laser treatment was performed by means of the Eye-Q excimer laser (wavelength=193 nm, pulse duration=12 ns, repetition rate=400 Hz) with the T-CAT software (Wavelight). The machine uses a flying spot laser of 0.95 mm in diameter with a Gaussian energy profile, 200 Hz repetition rate, and an active video-based 250-Hz eye-tracker. Immediately after laser ablation, a single topical application of mitomycin C 0.02 % (0.2 mg/ml) diluted in balanced salt solution was applied in each eye with a Weck sponge placed over the ablated stroma for 45 s. The corneal surface and the entire conjunctiva were then vigorously irrigated with 20 ml cold normal saline. At the end of the procedure, a bandage contact lens was applied which was removed after 1 week.

LASIK procedures were performed in a standardized manner. The cornea was marked with a corneal marker using gentian violet staining. If the flap was re-cut, the microkeratome settings (suction ring, flap stop) were chosen according to the steepest K (manufacturer's nomogram), aiming for maximum flap diameter. The M2 110 single-use head (Moria, Antony, France) was used for a desired cut depth of 130 μm and a superior hinge. After the microkeratome pass, the flap was lifted and folded onto itself. Intraoperative ultrasonic pachymetry was performed in all LASIK cases.

The ablations were made using the ALLEGRETTO WAVE excimer laser (WaveLight Laser Technologie AG). After performing the laser ablation, the flap was floated back into position, and the stromal bed was irrigated with balanced salt solution. Flap alignment was checked using gentian violet premarkings on the cornea, and a striae test was performed to ensure proper flap adherence. Postoperative medications included topical ciprofloxacin four times daily for 4 days and betamethasone four times daily for 7 days.

All patients instructed to wear UV protective sunglasses in direct sunlight for 3 months. Patients were examined at 1 day, 1 week, 1 month, 3 months, 6 months, and 12 months. Correspondingly, overall subjective quality of vision and frequency of visual symptoms (glare, halos, starbursts, ghosting, blur, night driving) were assessed by asking the patients.

Statistical analysis

The main parameters evaluated in this study included visual parameters: manifest refractive spherical equivalent refraction (MRSE), astigmatism, UCVA, BCVA, and asphericity. All parameters are expressed as means and standard deviation and were analyzed using a paired t test with software program SPSS (version 13.5). P value less than 0.05 is considered statistically significant.

Results

Twenty patients had topography-guided PRK for refractive errors, and eight patients had topography-guided LASIK. The mean preoperative MRSE was −4.88 D±1.03 (SD) in myopic eyes and 2.7±0.54 D in hyperopic eyes. The mean postoperative MRSE was −1.5±0.61 D in myopic eyes and 0.2±0.2 D in hyperopic eyes. The refractive results and the preoperative patient characteristics in each group are shown in Tables 1 and 2, respectively. In hyperopic and myopic eyes, the improvement in mean MRSE from pretreatment to 1 month and the last follow-up was statistically significant (P=0.02, P=0.003).

In the PRK group, mean UCVA improved from 0.34±0.16 or (20/60±20/120) (range 20/400 to 20/30) to 0.5±0.23 or (20/40±20/80) (range 20/200 to 20/20) at 12 months, and mean BCVA improved from 0.68±0.25 or (20/30±20/80) (range 20/60 to 20/20) to 0.76±0.23 (20/25±20/80) (range 20/25 to 20/20) at 12 months (Table 2). A statistically significant increase was noted in UCVA and BCVA at 12 months compared to the preoperative (P=0.01 and P=0.04, respectively). One patient lost one line of BCVA, 11 maintained their BCVA, and eight patients gained two lines or more of BCVA (Fig. 1).

In the LASIK group, mean UCVA improved from 0.2±0.19 or (20/100±20/100) (range 20/400 to 20/30) to 0.51±0.3 or (20/40±20/60) (range 20/200 to 20/20) at 12 months, whereas mean BCVA improved from 0.57±0.2 (20/40±20/100) (range 20/100 to 20/25) to 0.74±0.2 or (20/25±20/200) (range 20/60 to 20/20) at 12 months (Table 2). A statistically significant increase was noted in UCVA at 12 months compared to the preoperative UCVA (P=0.01), whereas the difference in BCVA was not statistically different. No patient lost any lines of BCVA; four patients gained two lines and more and all other patients maintained their BCVA (Fig. 1).

Refractive error for the PRK group improved from sphere 0.98±0.75 diopters (D) (range −4.75 to 8.25 D) to 0.38±0.49 D (range −3.5 to 0 D) (not significant) and from cylinder −2.25±0.39 D (range −0.25 D to −6.5) preoperatively to cylinder −1.5±0.23 D (range 0 to −3.5 D) postoperatively at 12 months, with a significant difference (P=0.008) (Tables 2 and 3) (Fig. 2). In the LASIK group, refractive error improved from sphere −1.90±2.08 D (range −12 to 5.5 D) to −0.93±0.82 D (range −5.5 to 2 D) at 12 months (not significant) and from cylinder −3.2±0.84 D (range −6 to 0.00 D) preoperatively to −2.06±0.42 D (range −3.5 to −0.5 D), reaching significance at 12 months postoperatively (P=0.07) (Tables 2 and 3) (see Fig. 2).

The relation equation in the topographic-guided ablation between amount of intended correction (X) and achieved correction (Y) was Y=0.82x+0.76 (R^2=0.57) in PRK group and Y=1.26x+1.29 (R^2=0.96) in LASIK group (Figs. 3 and 4). In the PRK group, corneal asphericity, as measured by the Q value, improved slightly from −0.9±0.15 (range −2.62 to −0.01) to −0.25±0.25 (range −2.19 to 1.40) at 12 months, without reaching statistical significance (Table 2). In the LASIK group, corneal asphericity changed from −0.65±0.19 (range −1.74 to −0.04) preoperatively to 0.13±0.45 (range −1.88 to 1.27) postoperatively, reaching not statistical significance.

Subjective symptoms, such as glare, halos, ghost images, starbursts, and monocular diplopia, although present in all cases preoperatively, were only reported postoperatively when specifically asked in the postoperative assessment. The mean changes in refraction with time for all patients are shown in Table 3.

Discussion

The application of refractive surgery following various corneal surgical procedures such as radial keratotomy or penetrating

Table 1 Visual parameters in the topographic- guided ablation group before treatment and 12 months after treatment (mean±SD) in all patients

Parameters		Preoperative	Postoperative	P value
Cylinder(D)		−3.5±3.3 (0.63)	−1.7±1.07	0.02
Spherical equivalent (D)	Myopic	−4.88±1.03	−1.5±0.61	0.003
	Hyperopic	2.7±0.54	0.2±0.2	0.01
BCVA		0.65±0.25	0.75±0.23	0.01
UCVA		0.31±0.18	0.5±0.25	0.0001
Mean keratometry		40.3±5.8	38.5±4.1	0.13
Asphericity (Q value)		−0.83±0.66	−0.13±0.22	0.02
Subjective rating of improvement in vision			1.42±0.507	

BCVA best corrected visual acuity, *UCVA* uncorrected visual acuity

Table 2 Topographic-guided PRK and LASIK outcomes

Parameters		Pretreatment		Posttreatment		*P* value pre- and postoperative	
Surgery type		PRK	LASIK	PRK	LASIK	PRK	LASIK
Eyes per group, *n*		20	8	20	8		
Mean±SE (D)	Myopic eyes	−2.8±0.72	−9.3±1.6	−1.09±0.58	−2.8±1.4	0.01	0.01
	Hyperopic eyes	2.7±0.65	3.00±1.2	0.59±0.66	−1.6±0.79	0.08	0.14
Mean astigmatism (D)		−2.25±0.39	−3.2±0.84	−1.5±0.23	−2.06±0.42	0.008	0.07
Pretreatment range of astigmatism (D)		−6.00 to 00	−6.00 to 00	−3.5 to 00	−3.5 to −0.5		
BCVA		0.68±0.25	0.57±0.26	0.76±0.23	0.74±0.24	0.04	0.15
UCVA		0.34±0.16	0.2±0.22	0.5±0.2	0.51±0.31	0.01	0.01
Mean keratometry		38.6±5.1	44.4±5.7	37.5±4.4	40.87±2.4	0.4	0.23
Asphericity (*Q* value)		−0.9±0.15	−0.65±0.19	−0.25±0.25	0.13±0.45	0.11	0.11

BCVA best corrected visual acuity, *UCVA* uncorrected visual acuity, *PRK* photorefractive keratectomy, *LASIK* laser-assisted in-situ keratomileusis

keratoplasty or refractive surgery is designed to optimize functional visual outcomes. The decision to perform refractive surgery following such procedures is determined by the objective visual result and the patient's subjective satisfaction. Enhancement rates and final refractive results are dependent on the surgeon's experience and nomogram predictability, as well as more subjective factors such as patient expectations. Our analysis of 28 eyes that had topography-guided PRK or LASIK for correction of myopia or hyperopia found major improvement in the preoperative refractive error (from −4.88± 1.03 D to −1.5±0.61 D in myopic eyes and from 2.7±0.54 D to 0.02±0.6 D in hyperopic eyes).

There are several published reports of conventional LASIK after corneal surgical procedures. The reported study by Afshari and coauthors [16] demonstrates a reduction from −3.93 D+/02.83 (SD) to −0.85±1.42 D in myopic eyes and from −1.43±1.79 D to −0.16±1.09 D in hyperopic eyes.

Our findings are in agreement with these studies and reveal an improvement in the mean MRSE from −9.3±1.6 D preoperatively to −2.8±1.4 D postoperatively in myopic eyes (P=0.01) and from +3.00±1.2 D preoperatively to −1.6±0.79 D postoperatively in hyperopic eyes (P=0.14). Two methods have better consequences in myopic patients (Table 2).

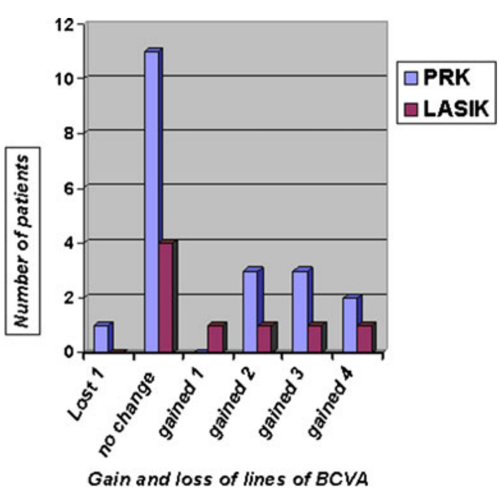

Fig. 1 Gain and loss of lines of BCVA at 12 months after topography-guided LASIK and PRK

Currently, the management of patients with irregular corneal astigmatism involves their wearing gas permeable contact lenses, the off-label use of procedures such as PRK and/or phototherapeutic keratectomy, and the Visx custom-contoured ablation pattern treatment. Ultimately, technological advances have led to two promising customized approaches: wavefront measurements [17–20] and corneal topography [21–24].

Topography-guided ablation for correction of irregular astigmatism has been debated. The results of various studies are summarized in Table 4. Compared with these other studies, with long duration of present study, lower percentages of eyes lost BCVA. Compared with the study of Jankov et al. [13], higher percentages of eyes gain two or more lines of BCVA. Allan et al. [25] explored the use of the Pulsar Z1 solid-state 213-nm photorefractive laser platform in topography-guided transepithelial PRK for irregular astigmatism. Compared with results of Allan et al. study, lower percentages of eyes lost lines of BCVA.

Lin et al. evaluated the clinical outcomes of custom topographic neutralizing technique in treating highly aberrated eyes using the WaveLight ALLEGRETTO WAVE Excimer Laser retrospectively and reported that safety was acceptable for small optical zone and decentered ablation retreatments, but the algorithms for custom topographic neutralizing technique need further refinement [26]. The major disadvantage of topography-guided ablation comes from the same fact that it ignores the rest of the intraocular structures because it concentrates mainly on the corneal contour [27].

Dausch et al. reported on ten eyes with corneal irregularities from different causes, treated by means of videokeratography-controlled PRK. The high degree of haze reported by these

Table 3 Mean changes in refraction with time in all patients in diopters

SE					
	Patients		All	PRK	LASIK
Before surgery		Myopic eyes	−4.88±1.03	−2.8±0.72	−9.3±1.6
		Hyperopic eyes	2.7±0.54	2.7±0.65	3.00±1.2
After surgery	1 month	Myopic eyes	−1.7±0.5	−1.1±0.8	−2.9±0.8
		Hyperopic eyes	−0.1±0.6	0.5±1.0	−1.9±0.1
	6 months	Myopic eyes	−1.6±0.7	−1.00±0.7	−2.8±1.0
		Hyperopic eyes	−0.1±0.7	0.6±1.0	−1.8±0.3
	12 months	Myopic eyes	−1.5±0.61	−1.09±0.58	−2.8±1.4
		Hyperopic eyes	0.02±0.6	0.59±0.66	−1.6±0.79

PRK photorefractive keratectomy, *LASIK* laser-assisted in situ keratomileusis

authors in the only patient treated for astigmatism after PKP may be related to the large spot size of the excimer laser used [28].

Our outcomes showed a trend of undercorrection of the sphere and astigmatism in most cases. The data of Wicsingcr-Jendritza et al. [29] and Knorz and Jendritza [21] about LASIK treatment featured a high percentage of undercorrection and regression caused by underestimation of corneal irregularity.

Several authors recommend deliberate spherocylindrical undercorrection in topographic PRK [30]. Because with presence of significant irregular astigmatism the manifest refraction endpoint is often not clear and also variable, thickness epithelial masking [31, 32] and differential ablation rates may contribute additional uncertainty.

Kymionis et al. [22] reported a general increase in UCVA and BCVA and better recentration of previously decentered ablations, without a significant change in spherical equivalent with a flying spot laser. Good results were shown by Alió et al. [33] with TOPOLINK LASIK in patients with a recognizable topographic pattern while the superficial surface quality, as well as BCVA, actually worsened in the group with irregular astigmatism. In our study, BCVA improved or unchanged in most patients.

Alessio et al. [23, 24] performed topography-guided PRK in patients with decentered myopic ablation and irregular astigmatism after PKP and reported a significant decrease in sphere and cylinder and a gain in BCVA in all patients with irregular astigmatism and 50 % of patients with decentered ablation. In our study, the postoperative decrease in cylinder and sphere equivalent was statistically significant (Tables 1 and 2).

The issue of epithelial removal ahead of topo-guided custom ablation PRK revealing stromal surface, which is different from the corneal surface with the epithelium on (due to epithelial remodeling in corneas with irregular astigmatism) and the PRK, incites a greater healing response than LASIK and PRK was chosen as opposed to LASIK especially in topography-assisted ablation where the results would be less predictable. Prophylactic use of mitomycin-C (MMC) after PRK now appears to prevent corneal haze safely and effectively, and PRK with intraoperative topical

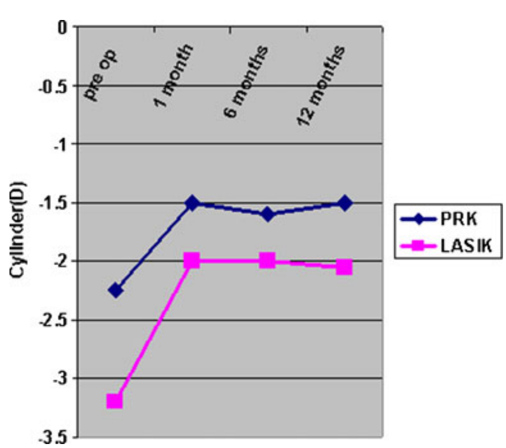

Fig. 2 Mean change in astigmatism shown in diopters (D) with time after topography-guided PRK and LASIK

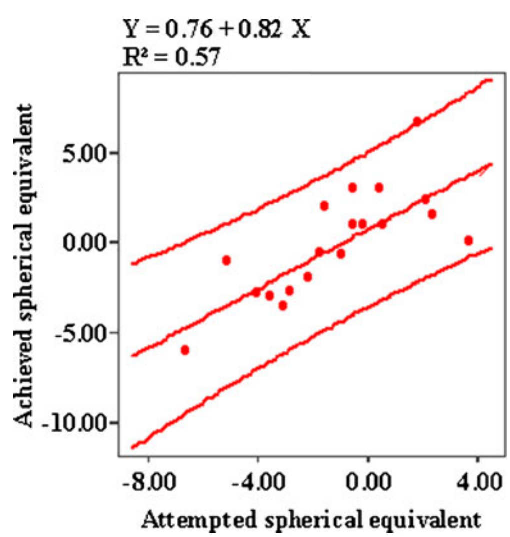

Fig. 3 Correlation between attempted versus achieved spherical equivalent in PRK group

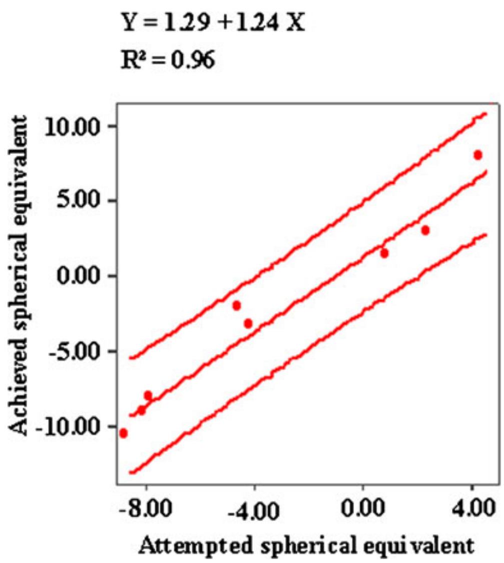

Fig. 4 Correlation between attempted versus achieved spherical equivalent in LASIK group

MMC is increasingly applicable in these high-risk patients [34, 35].

Considering the expected imprecision regarding the refraction, it is important to evaluate the gain and loss of lines of BCVA. Indeed, all of the studies showed a moderate gain, whereas Kymionis et al. [22] and Alessio et al. [24] described a gain of up to five lines after LASIK and up to eight lines after PRK, respectively. In our series, there was a gain of up to four lines of BCVA; most of the patients maintained their BCVA, whereas one eyes lost one line of BCVA. The BCVA increased from 20/30 to 20/25 at 12 months. One patient in PRK group lost 1 line of BCVA in the follow-up, and it is related to more irregular cornea due to +1 corneal haze formation.

In our study, an UCVA ≥20/40 at 3 months was obtained by 54 %. Our study indicated higher predictability in eyes having topography-guided LASIK than topography-guided PRK.

The Q value was enhanced to −0.13±0.22 SD from −0.83± 0.66 SD and statistically was significant (P=0.02). In our study, the mean postoperative Q showed a shift toward more positive values compared with average physiological Q values.

Improvement in the overall quality of vision in most of the patients was noted. We did not encounter centration errors in this series because with the Wavelight system, both the topographic image and excimer laser centration are centered on the pupil using an active. Because no two irregular ocular surfaces are alike, designing a controlled study to compare different treatments for complications is difficult.

In this study, topography-guided PRK was successful in correcting most irregularities caused by previous refractive surgery and resulted in a significant reduction of refractive cylinder and increase of UCVA and BCVA (Table 2). Because information from the corneal topography and internal structures of the eye have not been incorporated into a single ablation profile, topography-guided treatment is expected to be a two-step procedure in the elimination of corneal irregularities and refractive error. Overall, this technique was shown to be a valuable method, and further studies of larger sample sizes and longer follow-up are warranted to further evaluate the role of this surgery in the management of patients with irregular astigmatism.

Table 4 Studies of topography-guided ablation outcomes for treatment of irregular astigmatism

Study	Type of surgery	Mean follow-up (months)	Eyes	UCVA		Loss of BCVA (%)	
				Preop	Postop	1 Line	>2 Lines
Knorz et al. [21]	TG LASIK	12	29 eyes postkeratoplasty (n=6)	20/200	20/150	n/a	n/a
			Posttrauma (n=6)	20/83	20/50		
			Decenter/small ablations (n=11)	20/60	20/50		
			Central islands (n=6)	20/70	20/60		
Alessio et al. [24]	TG PRK	8.4	10 eyes		>20/40 (70 %) >20/20 (30 %)	n/a	n/a
Kymionis et al. [22]	TG LASIK	9.22	11 eyes	20/50	20/28	n/a	n/a
Kanellopoulos [36]	TG LASIK		27 eyes	n/a	n/a	0	0
Jankov et al. [13]	TG LASIK	6	16 eyes LASIK (n=10)	20/130	20/39	0	0
	TG PRK		PRK (n=6)	20/157	20/53	16.6	0
Allan et al. [25]	TG PRK	12	14 eyes	n/a	n/a	14.2	
Current study	TG LASIK	12	28 eyes LASIK (n=8)	20/100	20/40	12.5	0
	TG PRK		PRK (n=20)	20/60	20/40	0	0

UCVA uncorrected visual acuity, *BCVA* best corrected visual acuity, *n/a* not applicable, *TG PRK* topography-guided photorefractive keratectomy, *TG LASIK* topography-guided laser-assisted in situ keratomileusis, *Preop* preoperation, *Postop* postoperation

Definition of terms

Best corrected visual acuity (BCVA): This is a measure of best acuity while wearing corrective lenses like glasses or contact lenses.

Corneal asphericity: The asphericity of the cornea is usually defined by determining the asphericity of the conicoid which best fits the portion of the cornea to be studied. The physiologic asphericity of the cornea shows a significant individual variation ranging from mild oblate to moderate prolate.

Conflict of interest Authors do not have any financial interest in the subject matter of this article.

References

1. Febbraro JL, Buzard KA, Friedlander MH (2002) Reoperations after myopic laser in situ keratomileusis. J Cataract Refract Surg 26:41–48
2. Schallhorm SC, Kaupp SE, Tanzer DJ, Tidwell J, Laurent J, Bourque LB (2003) Pupil size and quality of vision after LASIK. Ophthalmology 110:1606–1614
3. Pop M, Payette Y (2004) Risk factors for night vision complaints after LASIK for myopia. Ophthalmology 111:3–10
4. Perez-Santonja JJ, Ayala MJ, Sakla HF, Ruiz-Moreno JM, Alio JL (1999) Retreatment after laser in situ keratomileusis. Ophthalmology 106:21–28
5. Hersh PS, Fry KL, Bishop DS (2003) Incidence and associations of retreatment after LASIK. Ophthalmology 110:748–754
6. Yavitz E (2002) PRK retreatments after regressed myopic LASIK. Ophthalmology 109:1953–1954
7. Carones F, Vigo L, Carones AV, Brancato R (2001) Evaluation of photorefractive keratectomy retreatments after regressed myopic laser in situ keratomileusis. Ophthalmology 108:1732–1737
8. Qi H, Xia Y, Chen Y, Zhu X (2002) Excimer retreatment for undercorrection or regression after laser in situ keratomileusis [Chinese]. Zhonghua Yan Ke Za Zhi 38:72–75
9. Lyle WA, Jin GJ (2000) Retreatment after initial laser in situ keratomileusis. J Cataract Refract Surg 26:650–659
10. Bilgihan K, Ozdek SC, Akata F et al (2000) Photorefractive keratectomy for post-penetrating keratoplasty myopia and astigmatism. J Cataract Refract Surg 26:1590–1595
11. Hardten DR, Chittcharus A, Lindstrom RL (2004) Long term analysis of LASIK for the correction of refractive errors after penetrating keratoplasty. Cornea 23:479–489
12. Buzard K, Febbraro IL, Fundingsland BR (2004) Laser in situ keratomileusis for the correction of residual ametropia after penetrating keratoplasty. J Cataract Refract Surg 30:1006–1013
13. Jankov MR 2nd, Panagopoulou SI, Tsiklis NS, Hajitanasis GC, Aslanides M, Pallikaris G (2006) Topography-guided treatment of irregular astigmatism with the wavelight excimer laser. J Refract Surg 22(4):335–344
14. Manns F, Ho A, Parel JM, Culbertson W (2002) Ablation profiles for wavefront guided correction of myopia and primary spherical aberration. J Cataract Refract Surg 28:766–774
15. Probst LE, Machat JJ (1998) Conservative photorefractive keratectomy for residual myopia following radial keratotomy. Can J Ophthalmol 33(1):20–27, Feb
16. Afshari NA, Schirra F, Rapoza PA, Talamo JH, Ludwig K, Adelman RA, Kenyon KR (2005) Laser in situ keratomileusis outcomes following radial keratotomy, astigmatic keratotomy, photorefractive keratectomy, and penetrating keratoplasty. J Cataract Refract Surg 31(11):2093–2100
17. Kanjani N, Jacob S, Agarwal A, Agarwal A, Agarwal S, Agarwal T, Doshi A, Doshi S (2004) Wavefront- and topography-guided ablation in myopic eyes using Zyoptix. J Cataract Refract Surg 30:398–402
18. Gimbel HV, Sofinski SJ, Mahler OS, van Westenbrugge JA, Ferensowicz MI, Triebwasser RWJ (2003) Wavefront-guided multipoint (segmental) custom ablation enhancement using the Nidek NAVEX platform. J Refract Surg 19:S209–S216
19. Mrochen M, Krueger RR, Bueeler M, Seiler T (2002) Aberration-sensing and wavefront-guided laser in situ keratomileusis: management of decentered ablation. J Refract Surg 18:418–429
20. Carones F, Vigo L, Scandola E (2003) Wavefront-guided treatment of abnormal eyes using the LADARVision platform. J Refract Surg 19:S703–S708
21. Knorz MC, Jendritza B (2000) Topographically-guided laser in situ keratomileusis to treat corneal irregularities. Ophthalmology 107:1138–1143
22. Kymionis GD, Panagopoulou SI, Aslanides IM, Plainis S, Astyrakakis N, Pallikaris IG (2004) Topographically supported customized ablation for the management of decentered laser in situ keratomileusis. Am J Ophthalmol 137:806–811
23. Alessio G, Boscia F, La Tegola MG, Sborgia C (2001) Topography-driven excimer laser for the retreatment of decentralized myopic photorefractive keratectomy. Ophthalmology 108:1695–1703
24. Alessio G, Boscia F, La Tegola MG, Sborgia C (2001) Corneal interactive programmed topographic ablation customized photorefractive keratectomy for correction of postkeratoplasty astigmatism. Ophthalmology 108:2029–2037
25. Allan BD, Hassan H (2013) Topography-guided transepithelial photorefractive keratectomy for irregular astigmatism using a 213 nm solid-state laser. J Cataract Refract Surg 39(1):97–104
26. Lin DT, Holland SR, Rocha KM, Krueger RR (2008) Method for optimizing topography-guided ablation of highly aberrated eyes with the ALLEGRETTO WAVE excimer laser. J Refract Surg 24(4):S439–S445
27. Campbell C (2001) Corneal topography in corneal ablations. In: McRae SM, Krueger RR, Applegate RA (eds) Customized corneal ablation: the quest for supervision. Slack, Thorofare, pp 229–236
28. Dausch D, Schroder E, Dausch S (2000) Topography-controlled excimer laser photorefractive keratectomy. J Refract Surg 16:13–22
29. Wicsingcr-Jendritza B, Knorz MC, Ilugger P, Liermann A (1998) Laser in situ keratomileusis assisted by corneal topography. J Cataract Refract Surg 24:166–174
30. Pasquali T, Krueger R (2012) Topography-guided laser refractive surgery. Curr Opin Ophthalmol 23:264–268
31. Spadea L, Bianco G, Balestrazzi E (2004) Topographically guided excimer laser photorefractive keratectomy to treat superficial corneal opacities. Ophthalmology 111:458–462
32. Touboul D, Trichet E, Binder PS, Praud D, Seguy C, Colin J (2012) Comparison of front-surface corneal topography and Bowman membrane specular topography in keratoconus. J Cataract Refract Surg 38:1043–1049
33. Alió JL, Belda JI, Osman AA, Shalaby AM (2003) Topography-guided laser in situ keratomileusis (TOPOLINK) to correct irregular astigmatism after previous refractive surgery. J Refract Surg 19:516–527
34. Majmudar PA, Forstot SL, Dennis RF et al (2000) Topical mitomycin-C for subepithelial fibrosis after refractive corneal surgery. Ophthalmology 107:89–94
35. Kim T, Pak JH, Lee SY, Tchah H (2004) Mitomycin C-induced reduction of keratocytes and fibroblasts after photorefractive keratectomy. Invest Ophthalmol Vis Sci 45:2978–2984
36. Kanellopoulos AJ (2005) Topography-guided custom retreatments in 27 symptomatic eyes. J Refract Surg 21(5):S513–S518